SE/

NATIONAL BUREAU OF STANDARDS REPORT

3493

STATISTICAL ANALYSIS OF EXPERIMENTAL PARACHUTE TEST DATA

by

D. Teichroew

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE

Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS

A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section is engaged in specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside of the back cover of this report.

Electricity. Resistance Measurements. Inductance and Capacitance. Electrical Instruments. Magnetic Measurements. Applied Electricity. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Gage.

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenics. Engines and Lubrication. Engine Fuels. Cryogenic Engineering.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Measurements. Infrared Spectroscopy. Nuclear Physics. Radioactivity. X-Rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. Atomic Energy Commission Instruments Branch.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Aerodynamics. Engineering Mechanics. Hydraulics. Mass. Capacity, Density, and Fluid Meters.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure. Chemistry of Mineral Products.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Machine Development.

Electronics. Engineering Electronics. Electron Tubes. Electronic Computers. Electronic Instrumentation.

Radio Propagation. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Frequency Utilization Research. Tropospheric Propagation Research. High Frequency Standards. Microwave Standards.

Ordnance Development.
Electromechanical Ordnance.
Ordnance Electronics.
These three divisions are engaged in a broad program of research and development in advanced ordnance. Activities include basic and applied research, engineering, pilot production, field testing, and evaluation of a wide variety of ordnance matériel. Special skills and facilities of other NBS divisions also contribute to this program. The activity is sponsored by the Department of Defense.

Missile Development. Missile research and development: engineering, dynamics, intelligence, instrumentation, evaluation. Combustion in jet engines. These activities are sponsored by the Department of Defense.

- Office of Basic Instrumentation
- Office of Weights and Measures.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT **NBS REPORT**

1101-40-5121 June 30, 1954 3493

STATISTICAL ANALYSIS OF EXPERIMENTAL PARACHUTE TEST DATA*

by

D. Teichroew

National Bureau of Standards

Final report on Project 1101-40-5131/54-7

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

I. Introduction

This report is the result of an investigation conducted under our Contract 1101-40-5131/54-7 (Navy Contract No. NPOLA NASSD-719). This contract was set up to provide "services to assist the Navy Parachute Unit by conducting a study of the results to be gained through statistical analysis of experimental parachute test data." The material for this report was obtained by the author in a visit to El Centro, January 11 to 15, 1954.

II. Recommendations

1. The major application of statistical theory to the work of the parachute testing facility should be in the design of the experiments, particularly those experiments which are conducted to determine the best one among a number of parachute types. The use of designed experiments should immediately provide more information about, and a better understanding of, factors which cause variability in parachute testing data. Eventually the accumulation of such information should permit statistically significant results to be obtained with smaller experiments.

2. The application of designed experiments would not cause any drastic change in the manner in which experiments are carried out at present. In fact, the experiments discussed later in this report would require only minor refinements to provide additional information.

3. Statistical analysis is concerned with random errors and cannot handle non-random errors. The data handling procedure should be

changed so that measurements are not so susceptible to human error. Another source of non-random error lies in the lack of precise definitions of concepts, for example, the recommendations from the reserve parachute system experiment are considerably affected by the definition of a failure.

4. Inasmuch as the amount of statistical work at the parachute testing facility is, at present, insufficient to occupy a statistician full time it is recommended that the facility acquire continuous consulting services to design and analyze experiments.

III. Discussion of Experiments

In the following discussion we shall make use of several statistical concepts. These concepts are explained in all standard texts and we need not take space here to describe them. For the sake of having something definite we shall use the book "Introduction to Statistical Analysis," by Dixon and Massey, published by McGraw Hill in 1951. In particular we shall use the technique known as "Analysis of Variance" described in Chapter 10, pp. 119-152, and the concept of a binomial distribution which is described on pp. 191-196.

The material and data used in the following discussion is taken from the reports describing the experiments.

1. Analysis of Data for Project TED ELC AE-5214

1. Table I indicates (i) that there is no essential difference in opening times between A and B, (ii) that there seems to be a consistent difference between B and C and that B is consistently lower than C.

2. The one discrepancy is that on the 11th C is lower than B. The opening time for this day had to be taken from movies taken at 200 f.p.s. The timing on this camera is considered unreliable and therefore the data must be treated with caution. It should be pointed out, however, that the opening times as taken by stop watches, also indicate that C was less than B on the 11th.

3. Table II gives the analysis of variance to test whether the difference between B and C is significant for the 20 drops at speed D for which reliable data is available. The observed F value is significant at the 5% level. From the analysis of variance it may be seen that both the day effect and the day by parachute type interaction are non-significant. A t-test, with the combined error estimate with 18 degrees of freedom, would therefore yield the same conclusion as the F test.

4. Table III gives the analyses of variance for C and B to test whether there is any difference between two parachutes of the same type. The tables clearly indicate that the variation between the two chutes of each type are very small.

5. The conclusion to be drawn from the fact that within-type variation is small is that no greater precision would be obtained by taking 5 drops of each of 4 chutes of each type than by making 10 drops of each of 2 chutes of each

type, as was made. On the other hand, no smaller precision would be obtained by using 4 chutes of each type and it might inspire more confidence that the chutes are a representative sample of their type.

6. The opening time of C at speed E indicates an erratic behavior. An examination of the motion pictures of the drops showed that each of the two parachutes tested had a deployment delay. These delays did not occur on the same day and therefore there is not immediate assignable cause for the delay.

Table I - Opening Time Totals for Two Parachutes of Each Type

	Parachute Type			
Day	A	B	C	Speed
11	3.61	4.04	3.65	D
14	4.78	4.79	5.04	D
16	4.92	4.83	5.21	D
17	4.87	4.20	4.91	D
18	4.61	4.67	5.08	D
18	-	4.70	5.44	D
21	-	5.50	6.00	E
29	4.75	4.92	6.37	E

Table II. Analysis of Variance to Test for Difference Between Types of Parachutes

	d.f.	SS	M.S.	F
Days	4	.1623	.0405	
Type of Parachute	1	.3100	.3100	5.973
Days x Type	4	.0467	.0115	
Error	10	.5190	.0519	

Table III. Analysis of Variance to Test for Differences Between Parachutes of the Same Type

	C			B	
	d.f.	SS		d.f.	SS
Days	4	.0807	Days	4	.1284
Parachutes	1	.0015	Parachutes	1	.0203
Days x Parachutes	4	.1350	Days x Parachutes	4	.3222

2. Analysis of TED ELC 525036 Data

The objectives of this experiment as stated in the introduction are: "... to ascertain their [four different personnel parachute canopy configurations] comparative performance with respect to stability, rate of descent, opening shock, and reliability." The data available could be analyzed statistically only for rate of descent and opening time.

From an examination of Table I - IV of Appendix B, it is clear that any such analysis would depend on a few values much different from the

others. For example, canopy I, 26 ft. dia. - 22 Gore Conical Type, was dropped 5 times during the test and the opening times were 1.75, 1.85, 3.2, 1.8, 1.75. It seems unreasonable to accept the 3.2 value as measuring the same thing as the other values; either it was measured incorrectly or something happened to the parachute on this drop. Unfortunately movies are not available to decide the question. It would be more meaningful to report the result of these five drops like this:

> The average opening time is $\frac{1}{4}(1.75 + 1.85 + 1.8 + 1.75)$ and in one out of five drops something happened which delayed opening time by 80%,

than to say merely:

> The average opening time is $\frac{1}{5}(1.75 + 1.85 + 3.2 + 1.8 + 1.75)$.

Clearly if the first method of reporting is used, comparison between types of parachutes will be affected by whether such delays occur or not.

The live jump program reported in Appendix D is probably the outstanding example of a place where a designed experiment could have yielded more conclusive results. In its present form the data presented in Appendix "D" cannot be analyzed statistically; the data is too incomplete, e.g., not even the number of jumps with each type of parachute is given. The use of ranking preference tests has increased greatly in recent years and all experience indicates that the tests must be very carefully designed to avoid bias. Every person has prejudices

and they may easily affect his judgment. In most tests the judge is not told which type of product he is testing; in parachute testing this is clearly impossible and therefore extra care must be taken to avoid bias.

It has also been shown that people cannot discriminate between many objects if they are not much different. In particular, people are better at ranking two objects than in ranking three. The more objects there are the more people tend to forget what the earlier ones were like. It is, therefore, important to randomize the order in which objects are testing. The conflicting testimony listed in Appendix D shows that the jumpers tend to forget, after a large number of jumps, what their experience in the first few jumps were.

3. Analysis if TED ELC 5206 Data

The major question in the analysis of this data is: what is meant by the failure of a system? On page 6 of report 5-53 appears the statement "It is noted that initial tests conducted in which the 200-inch line was employed resulted in a relatively low terminal velocity of the test assembly; thereby preventing complete deployment of the reserve parachute when released from its pack. Employment of the 200-inch reefing line was discontinued on all subsequent tests. ..." However the same situation, i.e., incomplete deployment of the reserve pack, was counted as a failure when it occurred with other reefing lines. There does not seem to be any reason why this should be counted against the system.

In listing "percent reliability" figures, as in Appendix C, Table 3, the number of tests involved in each figure should be given. Since

percent reliability is a binomial variate its variance can be computed once the number of tests is known. Tests of significance of the difference between two binomial variates can be made by the method given by Dixon and Massey, p. 193.

The failure of the attempt to correlate percent reliability and opening time is not surprising. In the first place, the percent reliability figures are ambiguous, as mentioned above. In the second place, the opening time measurements proved very inaccurate when compared with motion pictures. But most important is the fact that opening times were not divided into groups, namely those associated with tests which were successful and those which were not successful.

This experiment could also have profited from a scientific design. A start was made; the report, page 6 contains the statement, "It was believed that by testing the same parachutes without and then with pocket bands, a more significant and accurate comparison could be obtained between the two reserve parachute configurations." This belief is certainly correct, but no increase in significance can be obtained if the fact that the same parachutes were used is not used in the analysis, and in the analysis this fact is not used. The figure that should have been given is: how many reserve systems worked with pocket bands which did not work without them.

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.00). Information on calibration services and fees can be found in NBS Circular 483, Testing by the National Bureau of Standards (25 cents). Both are available from the Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS